NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
September 1944 as
Restricted Bulletin 4I15

EARLY DETECTION OF CRACKS RESULTING FROM FATIGUE STRESSING

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NACA

WASHINGTON

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RESTRICTED BULLETIN

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SUMMARY

Apparatus has been developed for detecting and measuring small changes in the deflection of a specimen in a rotating-beam fatigue machine. This change in deflection has been found to be a function of the size of the fatigue crack in the specimen. The correlation between deflection and crack size has been investigated. The apparatus may be used for indicating the formation of fatigue cracks or for following the progress of cracks as they propagate through the specimen.

INTRODUCTION

As one phase of a study of the evaluation of fatigue damage being made at the National Bureau of Standards, a method of detecting fatigue cracks at the earliest possible stage was desired. It was essential that the method should not involve continuous observation nor interruption of the test.

Preliminary experimentation with electrical and magnetic tests showed that any of these tests would be too difficult to set up and too susceptible to disturbance to be satisfactory in this application, particularly since most of the specimens to be tested were notched. Gensamer (reference 1) has used a microswitch operated by the deflection of the specimen to stop his fatigue machine in order to obtain cracked specimens, and it appeared that this method might be useful in fulfilling the above requirements.

This investigation, conducted at the National Bureau of Standards, was sponsored by, and conducted with financial assistance from, the National Advisory Committee for Aeronautics.

METHOD

The deflection of a rotating-beam specimen was measured throughout a test by using a cathetometer focused on the center of the specimen and illuminating the specimen with a stroboscope. The deflection changed rapidly during the early part of the test, then remained nearly constant throughout most of the run. When the deflection started to increase it was evident that fracture was imminent, as the deflection would increase at an increasing rate until the break occurred. However, the magnitude of the change was so small that it was obvious that a sensitive method of measurement was needed in order to obtain the desired results.

This is accomplished as follows: A micrometer screw mounted on the bed of the R. R. Moore machine is used to raise or lower a short piece of platinum wire to make contact with a plate of the same material mounted on, but insulated from, the specimen end of one bearing box. The contact is approximately 3/4 inch from the center of the specimen, and the deflection measured here is 85 to 90 percent of that at the center. These contacts are incorporated in the grid circuit of a gas triode tube as shown in figure 1. In this way the current through the contacts is kept very small so that no pitting or build-up of the surface can occur to change their dimensions. As soon as the micrometer contacts close, the grid potential is raised enough to allow the tube to conduct. This closes the relay in the plate circuit, which gives an audible or visual signal. Since the plate voltage is D. C., the tube continues to conduct until the plate voltage is reduced to zero by closing the key.

As the start of a test, the lower contact is raised by means of the micrometer screw until contact is made. This reading is noted, the screw backed off a certain amount, and the circuit reset for operation with the key. Then when deflection occurs, the alarm circuit is closed and can be opened only by backing off the screw and momentarily closing the key.

The gap left between the contacts is from 0.002 to 0.005 millimeter (0.0001 to 0.0002 in.) depending on the amount of extraneous vibration present. Since the data presented in this report were obtained, the whole fatigue machine has been mounted on tension springs designed to give it a natural period which is large in comparison with that of the disturbing vibration. It is now possible to get reliable operation with a gap of only about 0.001 millimeter (0.00005 in.). It is necessary to check the adjustment of the gap from time to time (about every 50 to 100 thousand cycles), as there are slow changes in deflection probably due to temperature changes.

After deflection of the specimen has started, the change of deflection may be measured with the micrometer contact, or the relay may be connected in such a way that the machine is automatically turned off when a predetermined value of deflection is reached.

MATERIAL AND TEST SPECIMENS

The material used in this work was normalized SAE X4130 steel having the following properties:

Hardness - Rockwell B 90

Yield strength (0.2 percent offset) - 62,500 psi

Ultimate tensile strength - 104,000 psi

Elongation (1 in.) - 27 percent

Reduction of area - 57 percent

Detailed dimensions of the reduced section of the specimen are shown in figure 2. The values of fatigue stress listed in this report are calculated on the minimum section, without regard to stress concentration. The speed of the fatigue machine was 3600 rpm.

RESULTS

In order to determine the relation between deflection and the area of the fatigue crack, specimens were run to various predetermined values of deflection. They were removed from the machine, heated 1 hour at 275° C to produce a dark blue temper color, and then broken in tension. The blue fractured area was in marked contrast to the bright fracture of the part broken in tension and showed very clearly the extent of the fatigue crack. The fracture of a typical specimen is shown in figure 3. The area of the crack was measured with a planimeter on an enlarged tracing of the fracture, and the results, plotted against the deflection in the fatigue test, are shown in figure 4. The deflections are plotted to a square-root scale, and the nearly linear relationship illustrates the primary difficulty with this method; that is, the deflection of the specimen caused by a small crack is extremely small.

As a point of incidental interest, figure 5 shows the values of tensile stress necessary to fracture the cracked fatigue specimens plotted against the remaining area. The sharp notch causes a large radial stress, thus increasing the resistance to plastic deformation.

As an example of the way in which the deflection-crack area relationship may be used, figure 6 shows the growth of fatigue cracks in several specimens at three different values of stress. No explanation is apparent for the differences in the rate of growth at one stress, as the rate shows no correlation with either the eccentricity of the crack or the number of cycles up to the beginning of cracking.

National Bureau of Standards,
Washington, D. C., July 27, 1944.

REFERENCE

1. Gensamer, Maxwell: Static Crack Strength of Metals. Metal Progress, vol. 38, July 1940, p. 59.

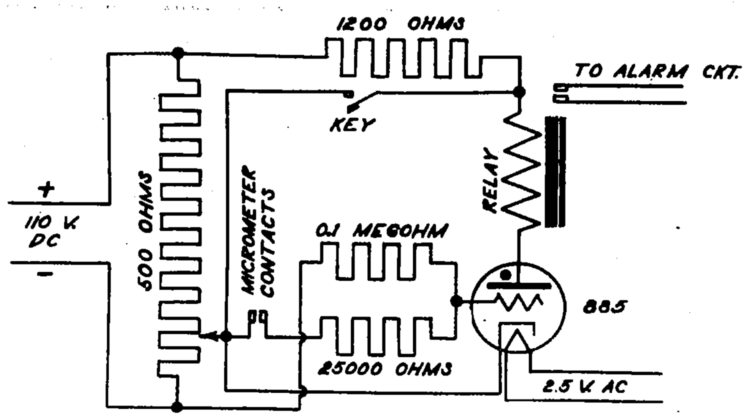

Figure 1.- Circuit diagram of the thyratron relay.

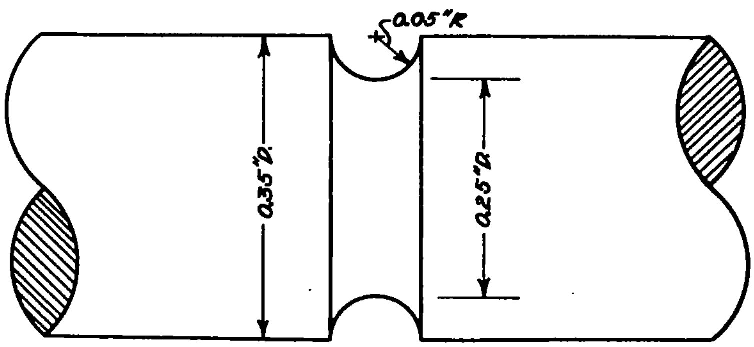

Figure 2.- Details of the reduced section of the fatigue specimen.

Figure 3.- Fractured specimen showing area of fatigue crack (dark), × 12.

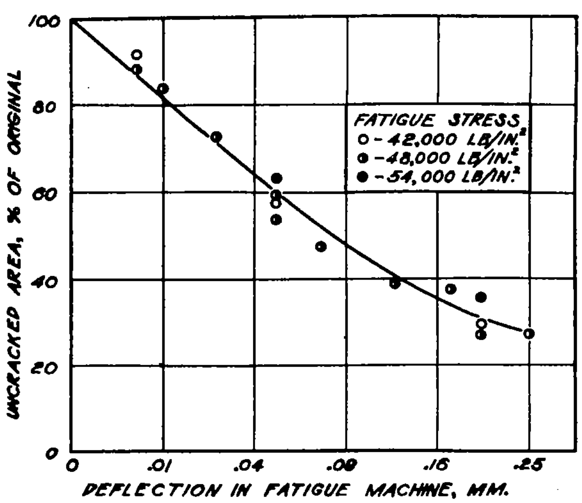

Figure 4.- Relationship between crack area and deflection. The latter is plotted to a square-root scale.

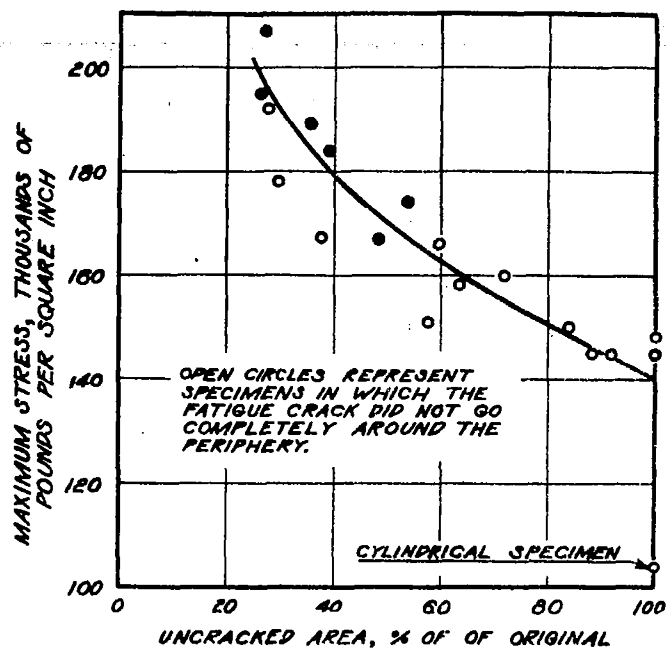

Figure 5.- Tensile stress necessary to fracture cracked specimens.

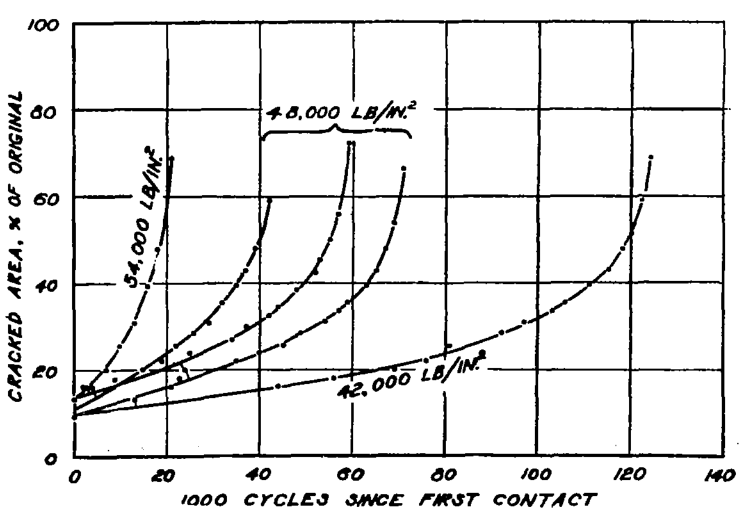

Figure 6.- Growth of fatigue cracks after first measurable deflection.